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Rethinking transport – towards clean and inclusive mobility

Toni Lusikka, (ed.)

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Abstract

This publication presents the proceedings of TRA2020, the 8th Transport Research Arena, which was planned to be held on 27-30 April 2020 in Helsinki. The physical conference event was cancelled due to the COVID-19 pandemic.

All work presented in this Book of Abstracts was peer-reviewed and accepted for the conference. Authors were encouraged to publish their full paper in a repository of their choice with a mention of TRA2020. Authors were invited to provide a link to the full paper to be included in this Book of Abstracts. If the link is not available, please contact the corresponding author to request the full paper.

Selection of TRA2020 papers were published in Special Issues of following journals: European Transport Research Review (Vol. 11-12) and Utilities Policy (Vol. 62 & 64).

Papers with a TRA VISIONS 2020 senior researcher winner as an author are marked with large yellow stars. Smaller stars stand for papers with an author shortlisted in the TRA VISIONS 2020 competition. The EC has supported the best senior researchers involved in EU projects with the TRA VISIONS awards.

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d Statens väg- & transportforskningsinstitut (VTI), Sweden
e Institut français des sciences et technologies des transports, de l'aménagement et des réseaux (IFSTTAR), France
** m.winter@uni-kassel.de*

Abstract

The Application of reclaimed asphalt is becoming increasingly important in the European Road Network. Beside the conventional recycling options (i. e. hot asphalt mixtures), cold recycling has been successfully applied in numerous road structures within the secondary and the main road network. However, the standard design procedures for common pavement materials as well as the approaches for cold recycling differ from one country to another. The comparison of five national pavement design procedures shows, that different design approaches may result in similar pavement structures for standard road materials (here: hot asphalt mixtures). The available specifications for pavement design with cold recycled materials indicate generally a surplus of thickness compared to standard structures. This varying surplus in thickness indicates different safety conditions applied in the analysed countries. In order to validate the existing pavement design procedures for cold recycling materials, two options will be followed. On the one hand mechanistic pavement design is applied which allows the calculation of required layer thicknesses. On the other hand, pavement design based on empirical values can be used.

Keywords: Recycling, Pavement design, Cold recycling bays layers

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701 Opportunistic sensing for road pavement monitoring

Bert De Coensel[a,b]*, Karlo Filipan[b], Wout Van Hauwermeiren[a], Joachim David[a], Luc Dekoninck[a], Toon De Pessemier[a], Wout Joseph[a], Luc Martens[a], Dick Botteldooren[a]

a WAVES Research Group, INTEC, Ghent University / imec, Technologiepark-Zwijnaarde 126, B-9052 Ghent, Belgium
b ASAsense CV, Spanjaardstraat 4, B-8000 Bruges, Belgium
** bert.decoensel@asasense.com*

Abstract

Road surface state monitoring is of main concern for road infrastructure owners. Hence dedicated measurement campaigns using laser scanning and image analysis are performed on a regular basis. Yet, this type of monitoring comes at a high labor cost and thus it is often limited in coverage and update frequency. This paper proposes opportunistic sensing as an alternative approach. Using sound and vibration sensing in cars that are on the road for other purposes and exploiting the advent of cheap communication, big data, and machine learning, timely information on road state is obtained. Results are compared to laser scanning for spatial frequencies between 0.1 and 100 cycles/m showing the applicability of the method. Results are also used for classification and labeling of road surfaces regarding their effect on rolling noise. Mapping illustrates the coverage of highways and local roads obtained in a few months with as few as seven cars.

Keywords: road surface; monitoring; noise; vibration; opportunistic sensing

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Bert De Coensel[a,b]*, Karlo Filipan[b], Wout Van Hauwermeiren[a], Joachim David[a], Luc Dekoninck[a], Toon De Pessemier[a], Wout Joseph[a], Luc Martens[a], Dick Botteldooren[a]

[a]*WAVES Research Group, INTEC, Ghent University / imec, Technologiepark-Zwijnaarde 126, B-9052 Ghent, Belgium*
[b]*ASAsense CV, Spanjaardstraat 4, B-8000 Bruges, Belgium*

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Keywords: road surface; monitoring; noise; vibration; opportunistic sensing.

* Corresponding author. Tel.: +32-475-377-801;
E-mail address: bert.decoensel@asasense.com

1. Introduction

Road surface state monitoring is of main concern for road infrastructure owners. Deteriorated road surfaces lead to higher noise emissions, and may even cause damage to vehicles or their cargo, which in turn may lead to damage claims. As road surfaces degrade over time, timely maintenance is required to prevent further damage, to maintain safe driving conditions, and to keep vehicle noise and vibrations within limits. Road administrators therefore use standardized measurement methods to monitor this degradation, such as laser scanning or close-proximity (CPX) noise emission measurements. However, performing these measurements is time consuming and requires specialized equipment. Hence, typically only major roads are covered, through ad hoc measurement campaigns. In practice, this implies that larger road infrastructure managers, such as regional or highway authorities, carry out measurements at most once in a year; in many cases only the rightmost lane is covered.

During the last couple of years, a number of alternative measurement methods have been developed, with the main goal of achieving a wider road coverage (Karlsson, 2014). A first approach is based on GPS and accelerometer data from smartphones, ideally attached to the dashboard of vehicles (Sattar et al., 2018). Examples of this approach are Nericell (Mohan et al., 2008), SRoM (Aleyadeh et al., 2015) or Roadroid (www.roadroid.com). Due to the large number of uncertainties related to smartphone measurements (e.g. unknown location and orientation of smartphone in the cabin), the accuracy obtained with this approach only allows to locate major potholes, and does not provide sufficient information on subtle changes in road wear, necessary for preventive maintenance. An alternative approach is based on the analysis of camera images performed while driving. An example of this approach is Sensovo (Van Geem et al., 2016), which uses dashboard cameras and accelerometers placed in regular vehicles.

This paper presents an opportunistic sensing approach to assess pavement degradation more efficiently in terms of cost, ease of deployment, data quality and spatial coverage, as compared to existing methods. The proposed approach is based on continuous monitoring of sound and vibration in the trunk of passenger cars, using a dedicated on-board unit. Confounders and modifiers, such as engine noise, the noise from passengers, vehicle speed and tire type, are removed by exploring the abundancy of acquired data. In the following sections, the methodology is presented, followed by the results from a pilot project, that show that the approach allows to distinguish different types of roads and their degradation.

2. Methodology

Road texture can be defined as the deviation of a pavement surface from a true planar surface, and is usually classified according to its longitudinal wave pattern. Irregularities can be defined on a micro, macro and/or mega scale (ISO 10844, 2014). On the one hand, the interaction between tires and pavement causes rolling noise (Sandberg and Descornet, 1980). Macrotexture interacts with the tire groves, giving rise to air-pumping effects, whereas megatexture causes tire vibrations. On the other hand, waviness and irregularity of the road surface also causes car vibrations (Cantisani and Loprencipe, 2010).

Within the proposed approach, sensor boxes equipped with a microphone, a tri-axial accelerometer and a GPS receiver are installed in the trunk of a fleet of passenger cars. For the present study, seven cars are used for a duration of about six months. Based on the raw accelerometer and microphone signals, 1/3-octave band spectra are calculated, in bands with central (temporal) frequency ranging from 1 Hz to 40 Hz for vibrations and from 25 Hz to 4 kHz for sound, in timeframes with a duration of 20ms. Both spectra are then concatenated, per timeframe, into a combined vibroacoustic spectrum, using linear weighting for the three overlapping 1/3-octave bands. Subsequently, these geo-located features are sent over a 3G connection to a server for further processing.

The response of the tire/car combination to the road surface texture obviously depends on the spatial wavelength λ, measured in m (or equivalent, the spatial frequency $\xi = 1/\lambda$, measured in cycles/m) and the driving speed υ (measured in m/s). Irregularities in road surface with a spatial frequency ξ will give rise to sound/vibration at temporal frequency $f = \upsilon \cdot \xi = \upsilon/\lambda$, when driven over at speed υ. The two most important modifiers, i.e. the transfer function of the vehicle and the driving speed, are removed from the measurements. The car transfer function relates the excitation of the tire to the measurement inside the trunk of the car, and is estimated, for each car individually, based on a large number of trips over a wide range of road surfaces. This approximation relies on the assumption that the tire excitation will be close to white noise if a random sample of the distribution of road surfaces, driving conditions and speeds is considered. After calibration, the estimated texture level $T''(i, \lambda)$, measured in dB (reference 1 μm), is obtained for every road segment i, and for a range of spatial wavelengths λ. As speeds between 30 km/h and 120 km/h are considered, and given the range of 1/3-octave bands mentioned above, the present approach focuses on the spatial wavelength range between 5cm (megatexture) and 10m (irregularity).

3. Results and discussion

Megastructure obtained from the system has been compared with results obtained through longitudinal laser measurements along the track of the right wheel of a measurement vehicle operated by the Belgian Road Research Institute (BRRI). These measurements were performed on 9 tracks of 1 km with different pavement types and different uses (local roads, major roads and highways). Results are shown as a function of spatial frequency per 1/3-octave band in Figure 1. The left pane shows the opportunistic sensing measurements *T''*, whereas the right pane shows the results directly obtained through the laser measurements T_l.

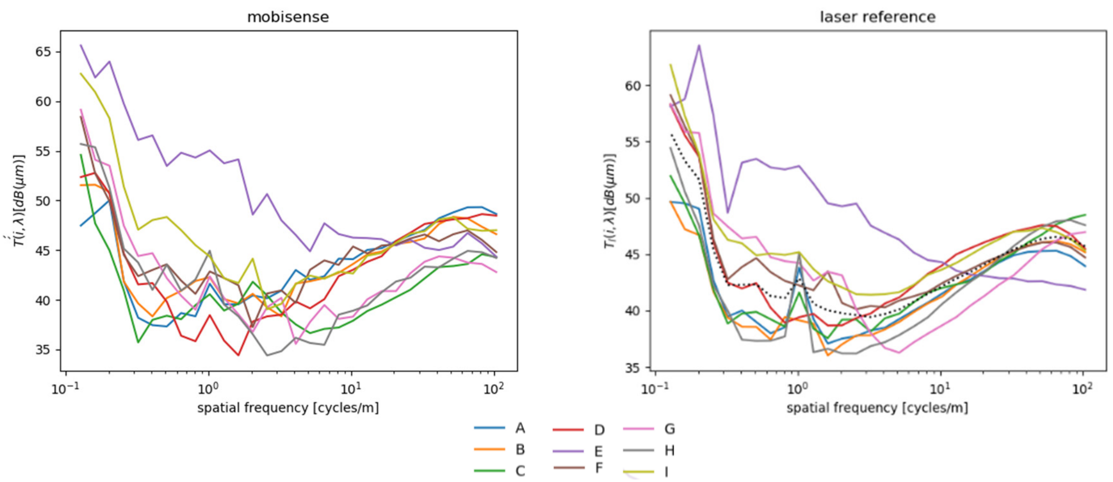

Figure 1: Texture level $\boldsymbol{T}$ (in dB, reference 1 μm), as a function of spatial frequency (calculated in 1/3-octave bands). Left: results of opportunistic measurements $\boldsymbol{T''(i, \lambda)}$, right: laser measurements $\boldsymbol{T_l(i, \lambda)}$. Results are shown for a range of road segments with different types of surfaces: dense asphalt concrete (A, B, C, D, F, H, I), stone mastic asphalt (G) and concrete plate pavement (E).

The laser measurements show a peak at 1 cycle/m which is due to resonance of the suspension of the measurement vehicle. Measurements close to 100 cycles/m made by the opportunistic method cannot be trusted due to the contact surface of the car tire. The outlier road stretch E is obvious in both measurements and corresponds to a rather old *concrete plate pavement*. At high frequencies, the laser measurements give a slightly lower texture amplitude due to a painted bicycle section that coincides with the laser measurement line. Road stretch G, a recently resurfaced *stone mastic asphalt* (SMA) on a local road, has a rather smooth megastructure at high frequencies, clearly visible in both measurement methods, but also has a higher low frequency irregularity due to its foundation, again clearly visible in both measurements. Road stretch D is a worn *dense asphalt concrete* (DAC) on a local road with high megastructure due to raveling and alligator cracks, visible in both measurements. A similar observation can be made about the DAC on road stretch I, a secondary road. The highway measurements A, B, and C show larger differences. For segments A and B, the opportunistic measurement approach indicates a stronger megastructure than the laser measurements, particularly in the range 2 to 30 cycles/m. On highway stretch C, the megastructure amplitude estimated with the opportunistic method is lower than that estimated with the laser method. However, it should be noted that road stretch C covers a bridge with joints at set distances that are clearly influencing the laser method more strongly. Based on this comparison, it could be concluded that the opportunistic method is a valuable alternative for classifying road surfaces according to their megastructure. For spatial frequencies below 1 cycle/m, the comparison is also good, but the laser measurements cannot be regarded as a good reference measurement in this frequency range as they might be influenced by the dynamics of the measurement vehicle.

As stated in the introduction, the opportunistic measurement method has the advantage that large amounts of data can be gathered at a relatively low cost. With approximately 7 cars of people living in the Ghent area, equipped with the measurement device, a good coverage could already be obtained for all major roads in the Ghent area in about three months. The amplitude in dB (ref 1mm) of the road structure at different wavelengths is shown in the maps of Figure 2. The maps also contain a classification of road segments according to the rolling noise an average vehicle would produce while driving on these roads. The road noisiness label is defined based on the sum of differences in dB over the 1/3-octave bands 350 Hz to 1250 Hz (David et al., 2019).

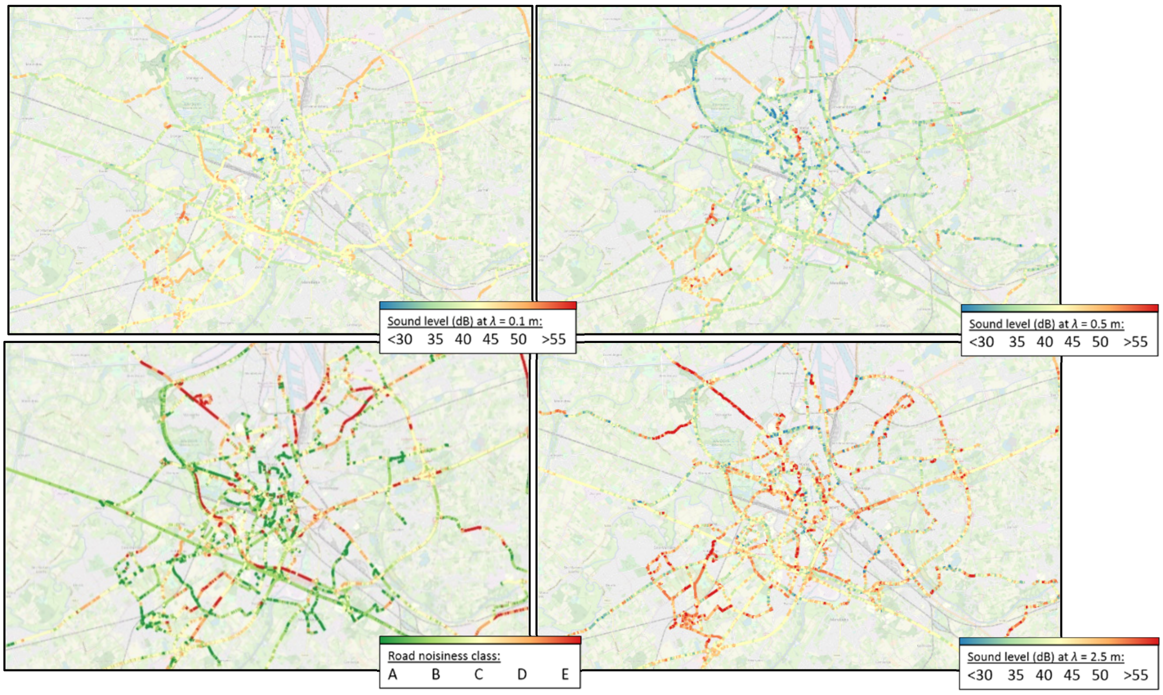

Figure 2: Examples of maps obtained from the opportunistic sensing method in the city of Ghent (clockwise from top right): megastructure level at $\boldsymbol{\lambda = 0.1}$**m**, at $\boldsymbol{\lambda = 0.5}$**m**, at $\boldsymbol{\lambda = 2.5}$**m**, and the road nosiness class.

4. Conclusions

Monitoring road pavement and foundation classically requires a large effort and therefore is not repeated very regularly and/or only on the primary roads. This paper introduced an opportunistic sensing method that is based on noise and vibration measurement on board vehicles that are on the road anyhow, combined with big data analysis. The presented approach makes use of small, dedicated sensor devices (microphone, accelerometer, GPS) placed in the trunk of vehicles, close to the rear wheel base, sturdily attached to the vehicle frame with well-known 3D accelerometer axes orientation. It is shown that, with the presented approach, the megastructure amplitude obtained corresponds to single-line laser measurements sufficiently good for a first classification to be a useful indicator of road surface state. At the same time a classification of road pavements with respect to their influence on rolling noise is obtained.

Installing the dedicated devices requires more initial effort than simply using smartphone apps (e.g. Roadroid), but once installed, the approach is effortless, as compared to current state-of-the-art measurement techniques such as laser scanning, which require dedicated driving campaigns. The main challenge with the presented approach is to find suitable vehicles to cover a spatial area; one could think of vehicle fleets of car sharing or taxi companies. Introducing the noise and vibration equipment in cars is on the other hand less intrusive and requires less maintenance than previously developed systems based on visual inspection (Van Geem et al., 2016). When compared to smartphone-based approaches, observations are obtained with a significantly higher continuity and reliability. Furthermore, thanks to the location of the microphone close to the wheel base, tire-road noise can be analyzed next to 3D acceleration, hereby significantly increasing the spatial frequency range (i.e. down to spatial wavelengths of 5cm).

Future work will include adding an expert system based on data driven machine learning to identify and localize specific road defects such as potholes, alligator cracks, etc. In a later stage, also an expert system can be added, which provides guidance to select the best road remediation approach, based on the measured state of the road pavement.

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References

Aleyadeh, S., Oteafy, S. M. A., Hassanein, H. S., 2015. Scalable transportation monitoring using the smartphone road monitoring (SRoM) system. Proceedings of the 5th ACM Symposium on Development and Analysis of Intelligent Vehicular Networks and Applications (DIVANet '15), Cancun, Mexico.

Cantisani, G., Loprencipe, G., 2010. Road roughness and whole body vibration: Evaluation tools and comfort limits. Journal of Transportation Engineering 136 (9), pp. 818-826.

David, J., Van Hauwermeiren, W., Dekoninck, L., De Pessemier, T., Joseph, W., Filipan, K., De Coensel, B., Botteldooren, D., Martens, L., 2019. Rolling-noise-relevant classification of pavement based on opportunistic sound and vibration monitoring in cars. Proceedings of the 48th International Congress and Exhibition on Noise Control Engineering (Internoise), Madrid, Spain.

ISO 10844, 2014. Specification of test tracks for measuring noise emitted by road vehicles and their tyres. International Organization for Standardization, Geneva, Switzerland.

Karlsson, R., 2014. Implementation of advanced monitoring techniques in road asset management – Results from the TRIMM project. Proceedings of Transport Research Arena 2014, Paris, France.

Mohan, P., Padmanabhan, V. N., Ramjee, R., 2008. TrafficSense: Rich monitoring of road and traffic conditions using mobile smartphones. Technical Report MSR-TR-2008-59, Microsoft Research India, Bangalore.

Sandberg, U., Descornet, G, 1980. Road surface influence on tire/road noise. Proceedings of the International conference on noise control engineering (Internoise), Miami, USA.

Sattar, S., Songnian, L., Chapman, M., 2018. Road surface monitoring using smartphone sensors: a review. Sensors 2018 (18), pp. 3845(1-21).

Van Geem, C., Bellen, M., Bogaerts, B., Beusen, B., Berlémont, B., Denys, T., De Meulenaere, P., Mertens, L., Hellinckx, P., 2016. Sensors on Vehicles (SENSOVO): Proof-of-concept for Road Surface Distress Detection with Wheel Accelerations and ToF Camera Data Collected by a Fleet of Ordinary Vehicles. Transportation Research Procedia 14, pp. 2966-2975.